PXIE RFQ Resonance Controller

System modeling and controller design

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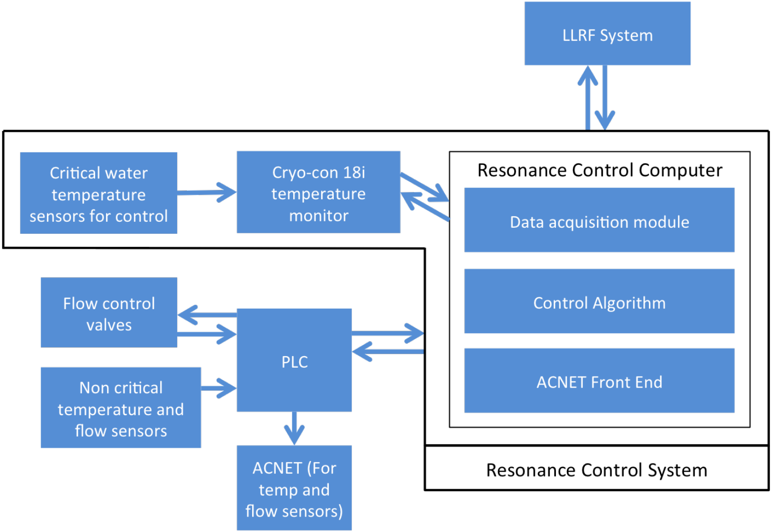
Overview

- Control system requirements
- Control system architecture
- Review of LBL modeling of the RFQ
- Overview of the water cooling system
- Modeling of the water cooling system
- Initial controls simulations
- Way forward

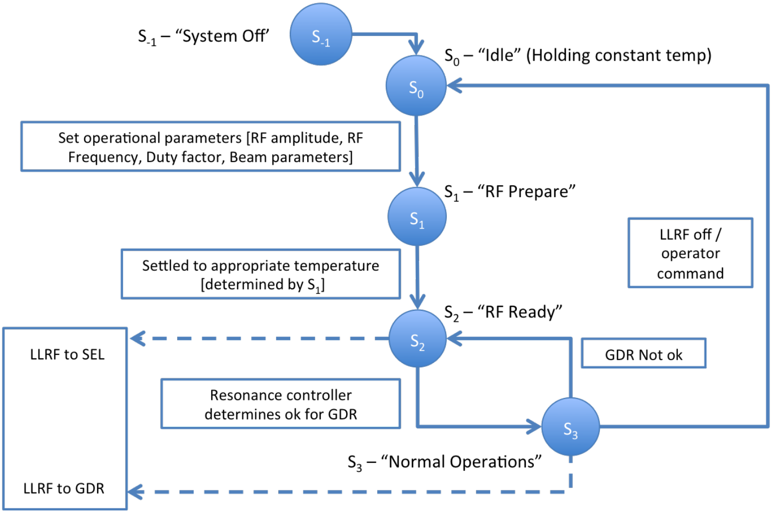
Control system requirements

- Keep reflected power below 20% in order to maintain cavity field with RF amplifiers
- Trip recovery time
  - Baseline: Recover in less then 10 times interruption time
  - Goal: Recover in less then 2 times interruption time
- Maximum recovery time (startup time)
  - Baseline: 30 minutes
  - Goal: 10 minutes

Control system architecture



State machine



Modeling and Simulation Effort

Review of LBL modeling of the thermal properties of the RFQ

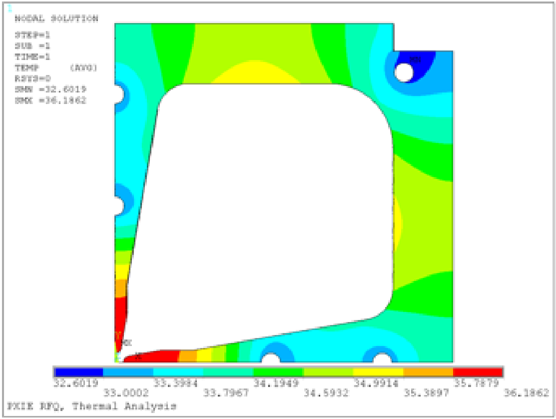


Figure: 2-D Electro-Thermal simulation (Andrew Lambert at LBL)

Review of LBL modeling of the thermal properties of the RFQ

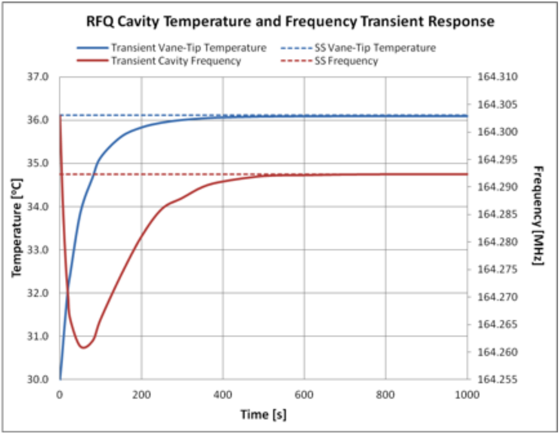
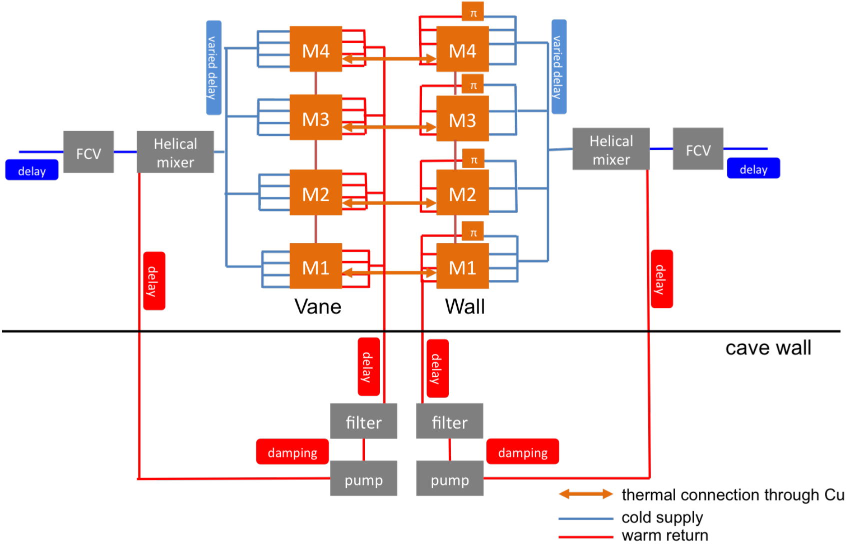


Figure: RF transient response due to different vane and wall response times, (Andrew Lambert LBL)

Water cooling system overview



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- Initial model (good for developing a general understanding)
    - RFQ is treated as two lumps of copper (vane and wall)
    - Vane and wall temperatures are coupled
    - Return temperature is mixed with cooler supply temperature
    - Pipe losses are modeled
    - Non-linear flow curve from valve is modeled
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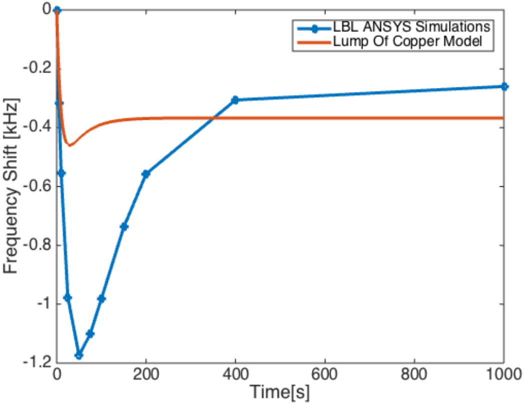
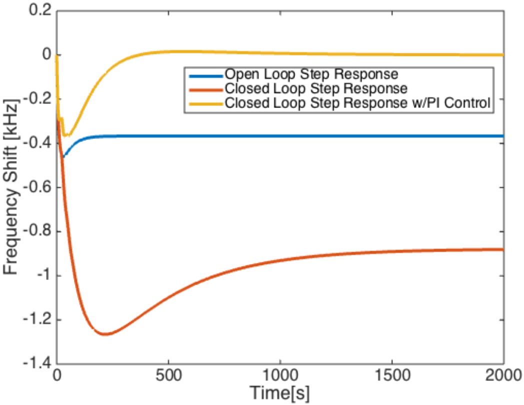
  - Pump heating is modeled
  - High degree of flexibility for additional complexity
- Higher fidelity numerical models (improved understanding of transient behavior: in progress)
  - Use to benchmark initial model
  - Possibly used later on for higher-fidelity control simulations

Comparison of initial model with LBL simulations



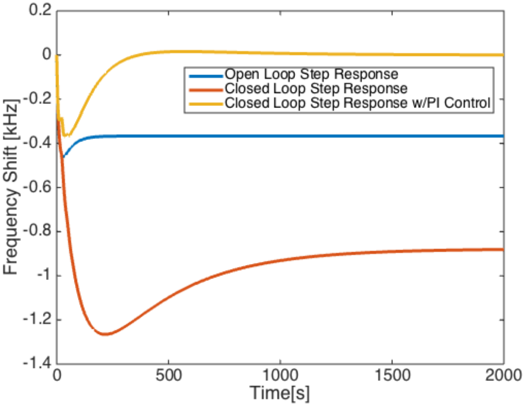
- Attempt to compare RFQ component of the cooling system model to the 2-D ANSYS simulations done by LBL
- Transient behavior is not well matched
- Steady state behavior is adequately matched

Initial model characterization with simple PI control (Step Response)



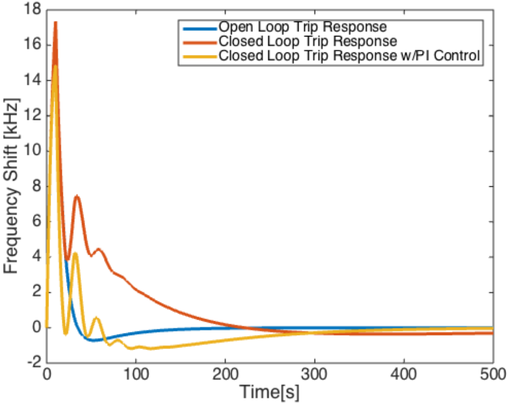
- At $t = 0$ the RF power increases by 2%
- Step response of the RFQ thermal model only (blue line)
- Step response of the whole water system (red line)
- Step response with a simple PI loop modulating the vane FCV on the resonant frequency error (yellow line)

Initial model characterization with simple PI control (Step Response)



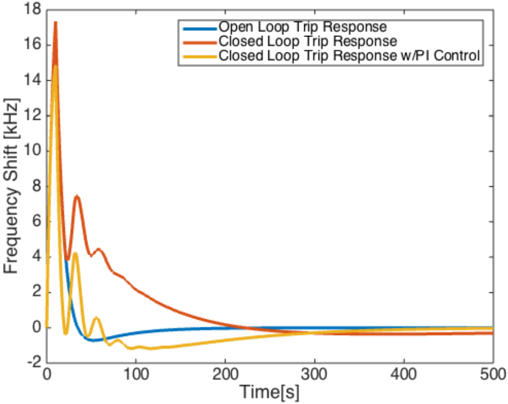
- Closed loop time constant longer then open loop
- A PI loop modulating just the vane FCV can keep the RFQ on resonance but the response time is too slow (need some sort of MPC)

Initial model characterization with simple PI control



- At $t = 0$ the RF power trips of for 10s
- Trip response of the RFQ thermal model only (blue line)
- Trip response of the whole water system (red line)
- Trip response with a simple PI loop modulating the vane FCV on the resonant frequency error (yellow line)

Initial model characterization with simple PI control



- Closed loop time constant longer then open loop
- Ripples in the trip response are due to temperature fluctuations in recirculating water
- A PI loop modulating just the vane FCV can keep the RFQ on resonance but the response time is too slow (need some sort of MPC)

Implementation Effort

Overview

- Data acquisition (communicate with Cryo-con 18i over Ethernet)
  - Program can request data using SCPI commands through a TCP socket
  - Archive of data is stored based on control algorithm needs

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  - Program can request data using SCPI commands through a TCP socket
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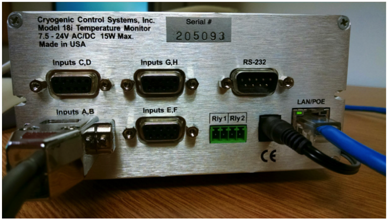
- Control system interfaces
  - LLRF system (SEL/GDR and cavity resonance information)
  - PLC (control actions to flow valve)
  - ACNET (general communication for high level control)

Cryo-con 18i temperature monitor



- Connects to up to 8 temperature sensors simultaneously
- Precision better than 0.01C
- Data available over Ethernet at a rate of 7.5 Hz

Data acquisition test over Ethernet

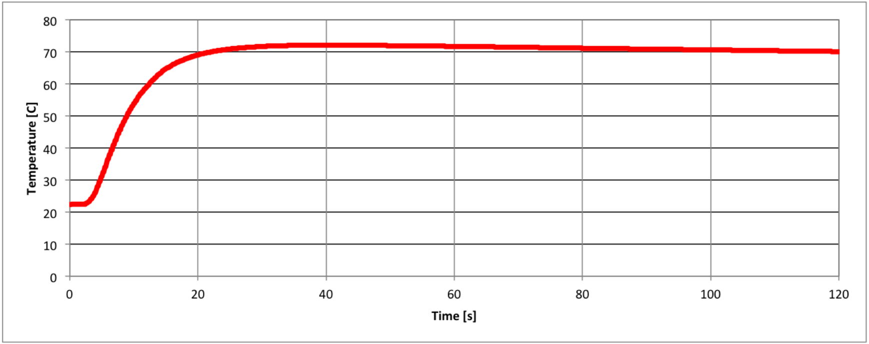


Figure: Sample data from RTD using Ethernet-CryoCon interface. Using python code and SCPI commands to communicate with the cryo-con over Ethernet we confirmed our ability to reliably communicate with this device

Way forward

- Initial development: from now until the RFQ water system is installed and operational
  - Assemble control system hardware
  - Develop and test communication to the PLC
  - Develop and test interface between control system and ACNET
  - Develop test plan for gathering data on the RFQ
  - Develop initial control algorithm based on system model
- Milestone: RFQ water system installed and operational
  - Test initial control system
  - Study water system for full design of resonance control system
  - Iterate on control algorithm using test data
- Milestone: Final resonance control system implemented